

**Composition for producing a barrier layer for gases**

The present invention relates to an organosilane-based composition for producing a barrier layer for gases. The invention also relates to a process for preparing the composition, and to use of the composition.

Plastics, processed to give foils or hollow articles, are increasingly used for producing packaging materials as a replacement for metals or glass. Plastics weigh less than glass and metals, and the amounts of materials required are smaller. Examples which may be mentioned of hollow articles made from plastics are the PET bottles composed of polyethylene terephthalate that are widely used nowadays. These are widely used by the drinks industry for bottling mineral waters or soft drinks.

The structure of packaging materials composed of plastic or of paper or paperboard gives them some degree of permeability for gases, water vapor, and flavors. This permeability inhibits the use of plastics packaging materials in sectors where particularly stringent requirements are placed upon barrier properties. In these sectors, permeability to gases and water vapor has to be reduced via barrier layers applied to the plastics materials.

The prior art discloses various coating materials for producing the barrier layer.

DE 196 50 286 C2 describes an inorganic-organic hybrid material (ORMOCER layer) on a backing material with at least 2 layers, where one layer is vapor-deposited  $\text{SiO}_x$  (100 nm), overlacquered with ORMOCER (3  $\mu\text{m}$ ).

WO 01/66653 A1 describes bisaminotrimethoxysilane in methanol as solvent for producing barrier layers on a backing material.

WO 01/66654 A1 and WO 01/66655 describe condensates derived from bisaminomethoxysilane or from other aminosilanes and from phenolic compounds in

methanol as materials for producing barrier layers.

WO 01/66656 A2 and WO 01/66662 describe preparations composed of a mixture of bisaminotrimethoxysilane and aminoethylaminopropyltrimethoxysilane with multi-functional acrylates and ethylenically unsaturated organic acids in methanol. The  
5 barrier layer is UV-cured.

WO 01/66661 A1 describes reactive silanes, ethylenically unsaturated acids, and polyethyleneimine in isopropanol.

10 US 5 077 135 (EP 0 313 252 A2, EP 0 392 115 A2; EP 476 202 A1, EP 0 505 274 A2) describes, for producing the coating material, silanes such as dimethyldimethoxy-, methyltrimethoxy-, methacryloxypropyltrimethoxy-, vinyltriethoxy-, and aminopropyltriethoxysilane, vinylbenzylaminosilane, and mixtures of these silanes in methanol as solvent.

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A feature common to all of these is the production of a barrier layer with barrier action with respect to gas and water vapor on plastic films (e.g. PE, PP) for packaging material.

20 Although the barrier layers disclosed in the prior art have some degree of barrier action with respect to gases and water vapor, it is desirable to make further improvement in the barrier action. It is therefore an object of the present invention to provide a composition which gives barrier layers with improved barrier action.

25 This object is achieved via an organosilane-based composition which comprises

- (i) at least one organoalkoxysilane whose organofunctionality displays at least one unsaturated hydrocarbon group,
- (ii) at least one aminoalkylalkoxysilane,
- 30 (iii) at least one polyol,
- (iv) optionally, another alkoxysilane or alkoxysiloxane, and
- (v) optionally, at least one nano- or microscale semimetal oxide or metal oxide,

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semimetal oxide hydroxide or metal oxide hydroxide, or semimetal hydroxide or metal hydroxide, and/or

(vi) at least one cocondensate composed of the components (i), (ii), (iii), and, optionally, (iv), and also, optionally, (v), and/or

5 (vii) reaction products produced under hydrolysis conditions from the components (i), (ii), (iii), and, optionally, (iv), and also, optionally, (v)

(viii) and organic solvent, with the proviso that there is a molar ratio (i) : (ii) : (iii) where (i) = 1 and (ii) = from 0.5 to 1.5, and (iii) = from 0.3 to 1.1.

10 The molar ratio (i) : (ii) is advantageously from 3 : 2 to 2 : 3.

The molar ratio (i) : (ii) : (iii) is advantageously 1 : 1 : 0.5 or 1 : 1 : 0.6 or 1 : 1 : 0.7 or 1 : 1 : 0.8 or 1 : 1 : 0.9 or 1 : 1 : 1 or 1 : 0.9 : 1 or 1 : 0.9 : 0.9 or 1 : 0.9 : 0.8 or 1 : 0.9 : 0.7 or 1 : 0.9 : 0.6 or 1 : 0.9 : 0.5 or 1 : 1.1 : 1 or 1 : 1.1 : 0.9 or 1 : 1.1 : 0.8 or 1 : 1.1 : 0.7 or 1 : 1.1 : 0.6 or 1 : 1.1 : 0.5 or 1 : 1.2 : 1 or 1 : 1.2 : 0.9 or 1 : 1.2 : 0.8 or 1 : 1.2 : 0.7 or 1 : 1.2 : 0.6 or 1 : 1.2 : 0.5.

The selection of component (i) is advantageously from the series vinyltrimethoxysilane, vinyltriethoxysilane, 3-methacryloxypropyltrimethoxysilane, 3-methacryloxypropyltriethoxysilane, 3-methacryloxypropylmethyldimethoxysilane, vinylmethyldimethoxysilane, vinylmethyldiethoxysilane, 3-methacryloxypropylmethyldiethoxysilane, 3-acryloxypropyltrimethoxysilane, 3-acryloxypropyltriethoxysilane, 3-acryloxypropylmethyldimethoxysilane, 3-acryloxypropylmethyldiethoxysilane.

25 Component (ii) is advantageously selected from the series 3-aminopropyltrimethoxysilane, 3-aminopropyltriethoxysilane, N-phenyl-3-aminopropyltrimethoxysilane, N-phenyl-3-aminopropyltriethoxysilane, N-butyl-3-aminopropyltrimethoxysilane, N-butyl-3-aminopropyltriethoxysilane, N-methyl-3-aminopropyltrimethoxysilane, N-methyl-3-aminopropyltriethoxysilane, N-(2-aminoethyl)-3-aminopropyltrimethoxysilane, N-(2-aminoethyl)-3-aminopropyltriethoxysilane, N,N-di(2-aminoethyl)-3-aminopropyltrimethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane, N,N-di(2-aminoethyl)-3-aminopropyltriethoxysilane, N-[N'-(2-

aminoethyl)-2-aminoethyl]-3-aminopropyltriethoxysilane, 3-aminopropylmethyldi-  
methoxysilane, 3-aminopropylmethyldiethoxysilane, N-butyl-3-aminopropylmethyl-  
dimethoxysilane, N-butyl-3-aminopropylmethyldiethoxysilane, N-(2-aminoethyl)-3-  
aminopropylmethyldiethoxysilane, N-(2-aminoethyl)-3-aminopropylmethyldiethoxy-  
5 silane, N,N-di(2-aminoethyl)-3-aminopropylmethyldimethoxysilane, N-[N'-(2-amino-  
ethyl)-2-aminoethyl]-3-aminopropylmethyldimethoxysilane, N,N-di(2-aminoethyl)-3-  
aminopropylmethyldiethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-amino-  
propylmethyldiethoxysilane.

10 Component (iii) is advantageously an aliphatic or aromatic polyol. Suitable compounds of this type are glucose, xylitol, mannitol, sorbitol, resorcinol, pyrogallol, hydroquinone, o-hydroxybenzoic acid (salicylic acid) or glycerol.

Component (iv) is advantageously selected from the series tetraethoxysilane,  
15 oligomeric tetraalkoxysilane, propyltrimethoxysilane, propyltriethoxysilane, octyltrimethoxysilane, octyltriethoxysilane, alcoholic and/or aqueous compositions of oligomeric cocondensates composed of aminoalkylalkoxysilanes and of fluoroalkylalkoxysilanes, and also oligomeric condensates or cocondensates composed of alkylalkoxysilanes and/or of vinylalkoxysilanes. The condensates or  
20 cocondensates may be prepared from, by way of example, propyltrimethoxysilane, propyltriethoxysilane, octyltrimethoxysilane, octyltriethoxysilane, vinyltrimethoxysilane, or vinyltriethoxysilane.

Component (v) is advantageously selected from the series silica, silicates, aluminum  
25 oxides, aluminum oxide hydroxides, aluminum hydroxide. The silica used may comprise precipitated or fumed silica. Examples of silicates are aluminosilicates, aluminum silicates, phyllosilicates, and the like. The aluminum oxide hydroxide used preferably comprises boehmite.

30 The organic solvent is advantageously a straight-chain or branched, aliphatic or cycloaliphatic or araliphatic or aromatic alcohol.

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If the composition is intended to be cured by UV radiation, it advantageously comprises a photoinitiator, its amount preferably being from 1 to 4% by weight, based on the total weight of the composition.

- 5 The solids content of the composition is advantageously from 10 – 60% by weight.

The invention also provides a process for preparing an organosilane-based composition for producing a barrier layer for gases. The process comprises

- 10 a) mixing together components (i), (ii), (iii), optionally (iv), optionally solvents and water, and permitting the mixture to react
- or
- b) forming an initial charge from components (i), (ii), and, optionally, (iv), heating the mixture, adding component (iii), optionally dissolved in a solvent, and adding water, and permitting the mixture to react at reflux
- 15 or
- c) forming an initial charge from components (i), (ii), optionally (iv), optionally solvents, and, optionally, component (v), with thorough mixing, heating the mixture, adding component (iii), optionally dissolved in a solvent, and adding water, and permitting the mixture to react at reflux
- 20 or
- d) dispersing fine-particle silica in vinylsilane, adding the other components, and reacting the mixture at room temperature or at reflux

where there is a molar ratio (i) : (ii) : (iii) where (i) = 1 and (ii) = from 0.5 to 1.5 and  
25 (iii) = from 0.3 to 1.1.

The solvent used preferably comprises alcohol, water, or an aqueous alcohol mixture.

30 In the inventive process it is advantageous to add activated carbon to the product mixture obtained after the reaction, and to filter the mixture and, optionally, remove solvent fractions from the filtrate.

The amount of water used per mole of silicon of components (i), (ii), and (iv) is advantageously from 0.5 to 1.8 mol, preferably from 0.85 to 1.8 mol, in particular from 1.3 to 1.4 mol.

The amount of component (v) advantageously used is from 0.01 to 40% by weight, preferably from 1.0 to 30% by weight, particularly preferably from 5.0 to 25% by weight, in particular using fumed silica in combination with glucose, xylitol, mannitol, sorbitol, resorcinol, pyrogallol, hydroquinone, salicylic acid, or glycerol, based on the entirety of components (i) to (iv).

The reaction of the components is preferably carried out at a temperature in the range from 10 to 90°C, preferably from 20 to 80°C, for a period of from 1 to 36 hours, preferably from 2 to 24 hours.

The invention also provides the use of the compositions described above for producing a radiation-cured barrier layer for gases, on a packaging material composed of plastic, paper, cardboard, or paperboard.

The invention also provides the use of the inventive composition for producing a radiation-cured barrier layer for gases, where, for further improvement in the barrier properties, at least one further coating capable of curing by a thermal, free-radical, or photochemical route is applied to the barrier layer.

The further coating applied, also termed coating composition or outer layer below, advantageously comprises a lacquer, in particular based on epoxy resin, and comprising not only a photoinitiator but also, as further components, at least one reaction product derived from fine pulverulent silicate, for example from a naturally occurring or modified clay or naturally occurring or modified phyllosilicate, in particular mica, and which comprises an organofunctional silane, in particular methacryloxypropyltrimethoxysilane, and water. A system particularly suitable as further coating is that found in the German parallel application with the title "Überzugsmittel zur Erzeugung einer Barrierschicht für Gase" [Coating composition for producing a barrier layer for gases].

The invention further provides the use as claimed in claims 15 to 20, and packaging materials as claimed in claims 21 to 24.

- 5 The lamellar metal pigments used in the inventive composition and/or in the coating composition may, by way of example, comprise the metal special-effect pigments known from paints technology, such as aluminum bronzes. This gives the articles coated with the coating composition a decorative appearance.
- 10 Another lamellar material which is neither a phyllosilicate nor a metal pigment but can likewise be used in the inventive coating composition is lamellar boron nitride.

The amount advantageously present of the lamellar particles is from 0.5 – 50% by weight, preferably from 20 – 30% by weight, based on the total weight of the coating  
15 composition.

The coating composition for the outer layer advantageously comprises, as further constituent, functional silanes. They serve as adhesion promoters to improve the adhesion between barrier layer and substrate. They also serve to modify the surface  
20 of the filler particles and the barrier layer. Examples of suitable functional silanes are meth- or ethoxysilanes, vinyl-, epoxy-, or aminofunctional silanes. Examples which may be mentioned are 3-aminopropyltriethoxysilane, 3-aminopropyltrimethoxysilane, 2-aminoethyl-3-aminopropyltrimethoxysilane, methyltrimethoxysilane, methyltriethoxy-  
25 silane, propyltrimethoxysilane, propyltriethoxysilane, isobutyltrimethoxysilane, isobutyltriethoxysilane, 3-glycidyloxypropyltrimethoxysilane, 3-glycidyloxypropyltriethoxysilane, 3-methacryloxypropyltrimethoxysilane, vinyltrimethoxysilane, 3-mercaptopropyltrimethoxysilane, bis(3-triethoxysilylpropyl)amine, N-(n-butyl)-3-amino-  
propyltrimethoxysilane, tetraethyl orthosilicate, ethyl polysilicate, vinyltriethoxysilane, octyltriethoxysilane, and hexadecyltrimethoxysilane.

30 The coating composition for the outer layer advantageously comprises, as further constituent, inorganic nanoparticles. These are inorganic fillers in fine-particle form,

where the particle size is in the nanometer range. These nanoparticles not only improve the flow properties of the coating composition but also contribute to an increase in the resistance to permeation by gases. Furthermore, they increase the mechanical stability of the barrier layers produced using the inventive coating composition. An example of a suitable material for achieving the abovementioned properties is fine-particle silica. It increases the viscosity of the coating composition and thus advantageously affects the stability of the same and the processing properties. In addition, the strength of the barrier coating is improved and its scratch resistance and abrasion resistance is increased. The commercially available fine-particle silica generally has a high level of agglomeration. This material should be deagglomerated to the greatest possible extent prior to or during incorporation into the inventive coating compositions.

The coating composition advantageously comprises, as further constituents, pigments and/or dyes for adjusting appearance and/or absorbing ultraviolet, visible, and infrared radiation. Pigments serve for coloring and permit adjustment of gloss and opacity of the barrier layers. UV absorbers and IR absorbers, and light-stabilizer additives, provide additional protection for the packaged product.

To adjust the processing properties of the coating composition for the outer layer, and to improve substrate wetting, the coating compositions may advantageously comprise modifiers, e.g. hydroxylated polybutadienes, fatty alcohols, polypropylene glycols, reactive monomers or reactive oligomers. To improve substrate wetting and water vapor barrier properties, use may be made of polybutadiene or 1-octanol, for example.

To improve wear resistance of the resulting barrier layer, use may be made of fillers, e.g. fumed silica or corundum.

The coating composition for the outer layer is prepared in accordance with the known technological rules, for example via simple mixing of the components and homogenization of the materials by means of a dissolver. If use is made of pigments,

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dyes, Aerosils, etc., it can be advantageous to use a bead mill to prepare a masterbatch paste. Advice from the raw material producers should be taken into account here.

5 The invention also provides the use of a coating composition described above for the outer layer for the coating of packaging materials composed of plastic, paper, cardboard, or paperboard, to produce a barrier layer for gases. The substrates to be coated are substrates which are to some extent permeable to substances transportable in gas form, for example gases, vapors, flavors, etc., or substrates  
10 intended to be protected from the abovementioned substances transportable in gas form. In this case, the resultant protective coatings therefore provide, in the widest sense, protection from corrosion. Suitable plastics substrates are, inter alia, polyethylene, polypropylene, biaxially oriented polypropylene, polyethylene terephthalate, polystyrene, polycarbonate. The plastics bottles composed of  
15 polyethylene terephthalate and increasingly used for the bottling of drinks are particularly important. Other suitable substrates are paper, cardboard, and paperboard. However, the inventive coating compositions can also be used to coat metals, such as iron, aluminum, copper, tin, zinc, and brass, and mineral substrates.

20 The substrates must be dry and free from grease for application of the inventive coating compositions. Prior rinsing with alcohol, such as isopropanol, may be necessary. In the case of plastics, adhesion to the substrate can be improved by corona pretreatment.

25 The inventive coating compositions for the outer layer are liquid materials which in principle can be processed by any of the available applications methods, such as spraying, flowcoating, dipping, roller coating, doctoring. Depending on the type of binder, UV radiation or electron beams are used to cure the coating composition on the substrate.

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The cured layers produced according to the invention are effective barriers with respect to substances transportable in gaseous form. These substances may be

gases in the relatively narrow sense, such as oxygen, nitrogen, carbon dioxide, sulfur dioxide, etc., or gases in the wider sense, such as vapors of water, of alcohols, of flavors, of amines, of aldehydes, of terpenes, etc. The good barrier properties generate numerous possible uses. The products equipped with an inventive barrier layer may be sheet-like or three-dimensional products composed of plastic or of paper materials, for example foils, papers, cardboard, paperboard, combinations of these materials, and hollow articles, such as bottles for the packaging of products which are sensitive to gaseous substances or which emit such substances, e.g. food, consumables, drinks, medicaments, or chemicals. The barrier layer provides protection from spoilage via chemical or physical effects and provides protection from the absorption of flavors and odors.

Examples are used below to provide further illustration of the invention.

**Inventive example 1**

**Mixture composed of methacryloxypropyltrimethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane and sorbitol (molar ratio 1 : 0.95 : 0.61)**

126 g of methacryloxypropyltrimethoxysilane and 126 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane form an initial charge in a 2.0 l multinecked flask, provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 65°C. By means of the dropping funnel, a mixture of 412.5 g of methanol and 80.1 g of a 70% strength aqueous solution of sorbitol are metered in with stirring within a period of from 50-60 min. This gives a clear, colorless liquid. The reaction mixture is heated at reflux for 1.5 hours. The product is then cooled and filtered through a glass fiber filter.

The siloxane-sorbitol mixture is a clear, yellowish, storage-stable liquid with a solids content of about 33% to DIN / EN ISO 3251.

To test barrier action, 90 ml of the siloxane-sorbitol mixture are treated, after dilution with methanol to a solids content of 15%, with 300 mg of Lucirin-TPO-L (BASF). PE foil of thickness 65  $\mu\text{m}$  is dipped into this liquid and air-dried. The foil is then run at minimum belt speed and max. lamp power through a laboratory UV system, using  
5 inertization with nitrogen (oxygen < 50 ppm). This gave a transparent layer of thickness about 3  $\mu\text{m}$  which had good adhesion. Oxygen permeation was 6  $\text{ml/m}^2 \text{ d bar}$  (0% r.h.).

### **Inventive example 2**

10 **Mixture composed of vinyltrimethoxysilane, N-[N`-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane and sorbitol (molar ratio 1 : 0.95 : 0.61)**

81.5 g of vinyltrimethoxysilane and 137.9 g of N-[N`-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane form an initial charge in a 2.0 l multinecked flask,  
15 provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 65°C. By means of the dropping funnel, a mixture of 329.1 g of methanol and 87.3 g of a 70% strength aqueous solution of sorbitol are metered in with stirring within a period of from 30-40 min. This gives a clear, colorless liquid. The reaction mixture is heated at reflux for 1.5 hours. The product is then cooled, treated with 0.1%  
20 of activated carbon, and filtered through a glass fiber filter.

The siloxane-sorbitol mixture after filtration is a clear, yellowish, storage-stable liquid with a viscosity of 9.5 mPa.s and a solids content of about 33.5% to DIN / EN ISO 3251.

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Barrier action was tested as stated in inventive example 1. Oxygen permeation with 2  $\text{ml/m}^2 \text{ d bar}$  (0 % r.h.).

### **Inventive example 3**

30 **Mixture composed of vinyltrimethoxysilane highly filled with Aerosil 380, N-[N`-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltriethoxysilane and sorbitol**

66.7 g of a vinyltrimethoxysilane<sup>x)</sup> filled with 25% by weight of Aerosil 380 formed an initial charge in a 2.0 l multinecked flask, provided with stirrer, reflux condenser, thermometer, and dropping funnel, and were heated to 70°C. The material is stirred at  
5 this temperature for 50 min and then cooled back to room temperature. 47.7 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane are then added. The resultant pale yellow, very slightly cloudy liquid is heated to 65°C. By means of the dropping funnel, a mixture of 203.5 g of methanol and 47.7 g of a 70% strength aqueous solution of sorbitol is then metered in with stirring within a period of 40 min.  
10 This gives a white liquid. The reaction mixture is heated at reflux for 8 hours. The product is then cooled and filtered through a glass fiber filter.

The siloxane-sorbitol mixture after filtration is a slightly cloudy, yellowish, storage-stable liquid with a solids content of about 35% to DIN / EN ISO 3251.

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Barrier action was tested as stated in inventive example 1. The PE foil was very effectively wetted. The transparent film gave an oxygen permeation of 1.4 ml/m<sup>2</sup> d bar (0% r.h.).

20 Comment:

x): The preparation of the vinyltrimethoxysilane filled with Aerosil 380 is described in the German patent application "Hochgefüllte Silan-Zubereitung" [Highly filled silane preparation], application No. 103 30 020.1, in inventive example 2.

25 **Inventive example 4**

**Mixture composed of vinyltriethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane and sorbitol (molar ratio 1 : 0.95 : 0.35)**

28.5 g of vinyltriethoxysilane and 37.8 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane form an initial charge in a 250 ml multinecked flask,  
30 provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are

heated to 70 - 75°C. By means of the dropping funnel, a mixture composed of 99.5 g of ethanol, 12.4 g of a 70% strength aqueous solution of sorbitol and 11.7 g of water is metered in with stirring within a period of 15 - 20 min. The resultant liquid is clear and pale yellow. The reaction mixture is heated at reflux for 1 hour. The product is  
5 then cooled and filtered through a glass fiber filter.

The siloxane-sorbitol mixture after filtration is a clear, yellowish, storage-stable liquid with a solids content of about 26% to DIN / EN ISO 3251.

10 Barrier action was tested as stated in inventive example 1. The transparent film, layer thickness 9.6  $\mu\text{m}$ , gave an oxygen permeation of 1  $\text{ml/m}^2 \text{ d bar}$  (0% r.h.) and 67.2  $\text{ml/m}^2 \text{ d bar}$  (50% r.h.).

#### **Inventive example 5**

15 **Mixture composed of vinyltriethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane and resorcinol (molar ratio 1 : 1 : 0.5)**

8.3 g of resorcinol dissolved in 100.5 g of ethanol and, in succession, 39.8 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane, and 28.5 g of  
20 vinyltriethoxysilane form an initial charge in a 250 ml multinecked flask, provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 75 - 80°C. 7.3 g of water are then added dropwise within a period of 5-10 min. The resultant liquid is lemon-yellow and clear. The mixture is heated at reflux for 1 hour. The product is then cooled and filtered through a glass fiber filter.

25 The siloxane-resorcinol mixture after filtration is a clear, orange, storage-stable liquid with a solids content of about 27% to DIN / EN ISO 3251.

Barrier action of the siloxane-resorcinol mixture was tested as stated in inventive  
30 example 1. The transparent film, layer thickness 9.0  $\mu\text{m}$ , gave an oxygen permeation of 6.7  $\text{ml/m}^2 \text{ d bar}$  (0% r.h.) and 1  $\text{ml/m}^2 \text{ d bar}$  (50% r.h.).

**Inventive example 6**

**Mixture composed of vinyltriethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane and resorcinol (molar ratio 1 : 1 : 1)**

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16.5 g of resorcinol dissolved in 100.5 g of ethanol and, in succession, 39.8 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane, and 28.5 g of vinyltriethoxysilane form an initial charge in a 250 ml multinecked flask, provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 75 -  
10 80°C. 7.3 g of water are then added dropwise within a period of 5-10 min. The resultant liquid is lemon-yellow and clear. The mixture is heated at reflux for 1.5 hours. The product is then cooled and filtered through a glass fiber filter.

The siloxane-resorcinol mixture after filtration is a clear, orange, storage-stable liquid  
15 with a solids content of about 30% to DIN / EN ISO 3251.

Barrier action of the siloxane-resorcinol mixture was tested as stated in inventive example 1. The transparent film, layer thickness 14.7 µm, gave an oxygen permeation of 1.1 ml/m<sup>2</sup> d bar (0% r.h.) and 4.5 ml/m<sup>2</sup> d bar (50% r.h.).

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**Comparative example 1**

**Mixture composed of methacryloxypropyltrimethoxysilane and N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane (molar ratio 1 : 0.95)**

25 114.4 g of methacryloxypropyltrimethoxysilane and 114.4 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane form an initial charge in a 2.0 l multinecked flask, provided with stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 65°C. By means of the dropping funnel, a mixture of 503.4 g of methanol and 22.0 g of water were metered in with stirring within a period of 20 min.  
30 This gives a clear, colorless liquid. The reaction mixture is heated at reflux for 1.5 hours. The product is then cooled and filtered through a glass fiber filter.

The siloxane mixture is a clear, yellowish, storage-stable liquid with a viscosity of 3.2 mPa.s and a solids content of about 23% to DIN / EN ISO 3251.

- 5 Barrier action was tested as stated in inventive example 1. The transparent film gave an oxygen permeation of 625 ml/m<sup>2</sup> d bar (0 % r.h.).

### **Comparative example 2**

- 10 **Mixture composed of vinyltriethoxysilane, N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane, and resorcinol (molar ratio 2 : 0.5 : 0.5)**

- 8.3 g of resorcinol dissolved in 115.4 g of ethanol and, in succession, 19.9 g of N-[N'-(2-aminoethyl)-2-aminoethyl]-3-aminopropyltrimethoxysilane, and 57.0 g of vinyltriethoxysilane form an initial charge in a 250 ml multinecked flask, provided with  
15 stirrer, reflux condenser, thermometer, and dropping funnel, and are heated to 75 - 80°C. 9.2 g of water are then added dropwise within a period of 5-10 min. The resultant liquid is lemon-yellow and clear. The mixture is heated at reflux for 1.5 hours. The product is then cooled and filtered through a glass fiber filter.

- 20 The siloxane-resorcinol mixture after filtration is a clear, orange, storage-stable liquid with a solids content of about 21% to DIN / EN ISO 3251.

- Barrier action of the siloxane-resorcinol mixture was tested as stated in inventive example 1. The transparent film, layer thickness 6.2 µm, gave an oxygen permeation of 750 ml/m<sup>2</sup> d bar (0% r.h.) and 420 ml/m<sup>2</sup> d bar (50% r.h.).

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### **Example of the preparation of the outer lacquer**

- 120.0 g of 3,4-epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate (commercial name UVACURE 1500; UCB Chemie GmbH) formed an initial charge in a 250 ml  
30 stainless steel disperser, and 40 g of phyllosilicate (commercial name MICA M; Merck KGaA) were incorporated with stirring (Dispermat) and dispersed at about 6000 rpm

for about 10 minutes. 4.5 g of bis(4-alkylaryl)iodonium hexafluoroantimonate (commercial name UV 9390 c; GE Bayer Silicones GmbH & Co KG) were then added with gentle stirring.

## 5 Usage example of foil lamination

**Composite structure: PET / outer lacquer / silane mixture / outer lacquer / PE**

The silane mixture used comprises a product as in inventive example 4. Outer lacquer / silane mixture / outer lacquer application gives an application weight of about 18 to 20 g/m<sup>2</sup>. The oxygen permeation was 5.6 ml/m<sup>2</sup> d bar (85% r.h.).

**Composite structure: OPP / outer lacquer / silane mixture / outer lacquer / PE**

Silane mixture as in inventive example 4 and outer lacquer give, at an application weight of about 18 - 20 g/m<sup>2</sup> an oxygen permeation of 4.7 ml/m<sup>2</sup> d bar for the composite structure at 85% r.h.